NATIONAL BUREAU OF STANDARDS REPORT

3380

MEASUREMENT OF STRAIN IN METHYL METHACRYLATE
CAUSED BY WATER SORPTION

by

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MEASUREMENT OF STRAIN IN METHYL METHACRYLATE CAUSED BY WATER SORPTION

Abstract

A method of determining the change in the internal residual strain in polymerized methyl methacrylate during its sorption of water has been developed. A bonded, wire strain gage embedded within the polymer is employed to determine the strain increments. Henry's and Fick's laws appear to be inapplicable for large specimens totally immersed in water. An assumption is made to the effect that the change in the strain is in a direct linear relationship to the amount of water sorbed. It is not believed that this assumption causes so great an error as to result in the contradiction of Henry's and Fick's laws.

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1. INTRODUCTION

The crazing of resins has been attributed mainly to the change in the characteristics of the internal residual strain in the resin during its action as an absorbent of water. For this reason the development of a method of determining the change in the internal residual strain in polymerized methyl methacrylate was desirable. Since the primary concern was with the internal effects, such strain gages as the Tuckerman, acoustical, etc., could not be used. The technique of photoelasticity was thought to be of practical use, but, since the specimens were to be placed in a water bath thereby making the determination of the change in the strain extremely difficult and since each specimen would have to be calibrated for the effective use of this technique, this method was discarded in favor of using bonded wire strain gages. The advantages of this type of gage lie in the remote measurement of the change in the strain and in the manufac-

urers calibration of the gages. There are, however, three major disadvantages in the use of these gages.

Since the change in the strain is determined by resistance measurements, any water sorption by the gage causing electrical leakage is detrimental to the results. Also excessive strains and temperatures will destroy their effectiveness, although the standard gages will withstand strains as high as 1% and temperatures up to 80°C for paper gages and 150°C for phenolic impregnated paper gages.(1) Finally the effective modulus of elasticity of the gages must be lower than that of the material in which they are to be used. The gage's modulus of elasticity may be lowered by the addition of laming of paper and cement to the surface of the gage.

The theory of the gage is based upon the phenomenon that a wire's resistance, to a first approximation, is directly proportional to a distortion along its longitudinal axis. Hence, any change in strain will result in a corresponding change in the resistance of the gage, both in sign and relative magnitude. The strain is determined from the gage factor which is determined by the manufacturer. The gage factor is defined by $K = \frac{dR/R}{dS}$, where K is the gage factor, R is the resistance of the gage and S is the strain.

METHOD

The gages used were the type designated by the manufacturer, Baldwin-Lima-Hamilton Corporation, as type A-5 with a gage factor of 1.99±1% and a resistance of 120±0.5% ohms. A photograph of the type of strain gage used is shown in Figure 1. The wheatstone bridge employed was the Baldwin-Lima-Hamilton Corporation's type L strain indicator which gives the readings directly in u in/in. This was complimented with their six channel switching and balancing unit

(1) Domestic price list, p. 4, July 15, 1953. Balwin-Lima-Hamilton Corp. Philadelphia 42, Pennsylvania.

which permits the use of six gages simultaneously and places the strain readings at the same fiducial point if desired. The arrangement of the apparatus is shown in Figure 2.

The mold used was formed by casting artificial stone around a brass master form, the gage leads being sealed in one wall. The mold was then linedwith 0.003" foil of pure tin as shown in Figure 3. A mix of methyl methacrylate polymer(1) and methyl methacrylate monomer(2) was then placed around the gage, pressure and heat were then applied to further polymerize the mixture. The specimens were cured for a period of twenty hours in an air bath at a temperature of 55°C. Since air has a low specific heat, the heat of polymerization of the resin cannot be removed rapidly enough to maintain a constant temperature within the specimen. To prevent any damage to the gage, the temperature must be kept below 80°C. Hence, it was necessary to use a low initiating temperature in order to keep the temperature within the specimen below the desired limit and eliminate any thermal damage to the gage. Since a flash type mold was used, the true pressure is not known, although it is estimated to be of the order of 2000 psi.

The positioning of the gage within the resin is shown in Figure 4.

The specimens having been cured and allowed to cool to room temperature, were removed from the mold and placed in a water bath at a temperature of 37°C ±0.1°. The specimens were then allowed 45 minutes to attain thermal equilibrium and the bridge balanced so that it registered a strain of 1000 u in/in. The changes in the strain were determined in the following manner: the first gage was placed in the bridge circuit by closing the corresponding switch in the switching and balancing unit and then given a thirty-second stabilizing period before the strain change was read from the strain indicator. Having determined

(1) Manufactured by E. I. duPont de Nemours and Co., Polychemicals Department, Washington, West Virginia. Color: H 7500 Composition HG41
(2) Manufactured by the Rohm and Haas Co., Philadelphia, Pa., with 0.006% Hydroquinone added as an inhibitor.

the strain change in the first specimen, the second gage was placed in the bridge circuit. This procedure was followed until all the strain increments were determined.

The thirty second stabilizing period was used to minimize the heating effects of current passing through the gage.

RESULTS AND CONCLUSION

The data obtained are shown plotted on a linear scale in Figure 5. As is to be expected, the initial time rate of change of strain is quite rapid and then tends to a constant value. Note that those specimens which have higher initial rates of change also level off more rapidly than those with lower time rates of change in strain.

Since Fick's and Henry's laws predict, for a membrane, a linear relationship between the logarithm of the quantity of water sorbed and the time, it was decided to plot a graph of the logarithm of the change in the strain against time, assuming that the change in strain was directly proportional to the amount of water sorbed, and determine if Fick's and Henry's laws were applicable to this case. A graph of specimen number 1 is shown in Figure 6 and is representative of all the other specimens.

Since there appeared to be no violent change in the curvature, it was decided to plot the strain change against the logarithm of the time. The curves obtained are shown in Figure 7. These rather surprising results were further amplified by expanding the ordinate in the central portion of the curves. This is shown in Figure 8.

In the regions amplified in Figure 8, the strain appears to be in a linear relationship to the logarithm of the time which is a contradiction of the prediction of Henry's and Fick's laws for the sorption of moisture by a membrane.

The contradiction of Fick's and Henry's laws is probably due to one, or both, of the following two reasons:

(1) Fick's and Henry's laws are not applicable to the type of specimens studied under the conditions of the experiment.

(2) The assumption that the strain change is in a linear relationship to the amount of water sorbed is false.

Although it is not likely that the change in strain is in a direct linear relationship to the water sorbed, it is not believed that the error caused by this assumption is so great as to cause a contradiction of the predictions of the general sorption laws. It therefore appears to be far more reasonable that the predictions of Fick and Henry are inapplicable to the type of specimens studied.

SUMMARY

The change in the internal residual strain of polymerized methyl methacrylate during water absorption was determined by embedding a bonded wire strain gage in the polymer. Henry's and Fick's laws were found to be inapplicable for the type of specimen under investigation.

References

1. Houwink, R., Elastomers and Plastomers, General Theory I, Elsevier Publishing Co., Inc., 1950, pp 321-4.

2. Dobie, W. B., and Isaac, P. C. G., Electric Resistance Strain Gages, English Universities Press, London, 1948.

3. Yarnell, J., Resistance Strain Gages; Their Construction and Use, Electronic Engineering, London, 1951.

4. Characteristics and Applications of Resistance Strain Gages, National Bureau of Standards Circular 528, issued February 15, 1954. (For sale by the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C.) (Price $1.50).

5. Circulars 279, 279A and 279B, Baldwin-Lima-Hamilton Corporation, Philadelphia 42, Pennsylvania.

6. Testing Topics, issued quarterly by Baldwin-Lima-Hamilton Corp., Philadelphia 42, Pennsylvania.

Figure 1. An enlargement of the type A-5 strain gage.

The length of the measuring portion of the gage is 1/2 inch, its width 15/64 inch. The overall dimensions of the gage body are 3/8 inch by 13/16 inch.

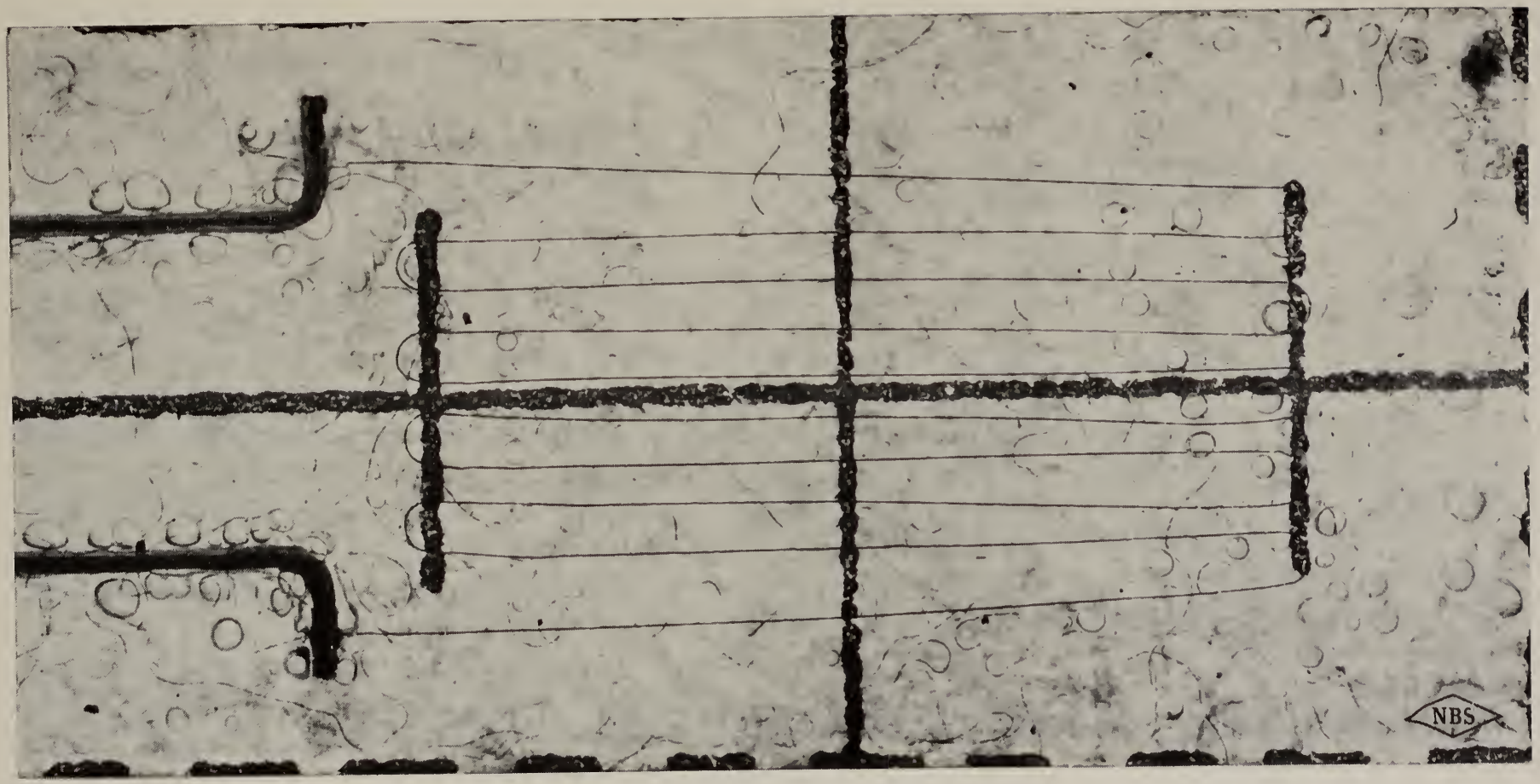
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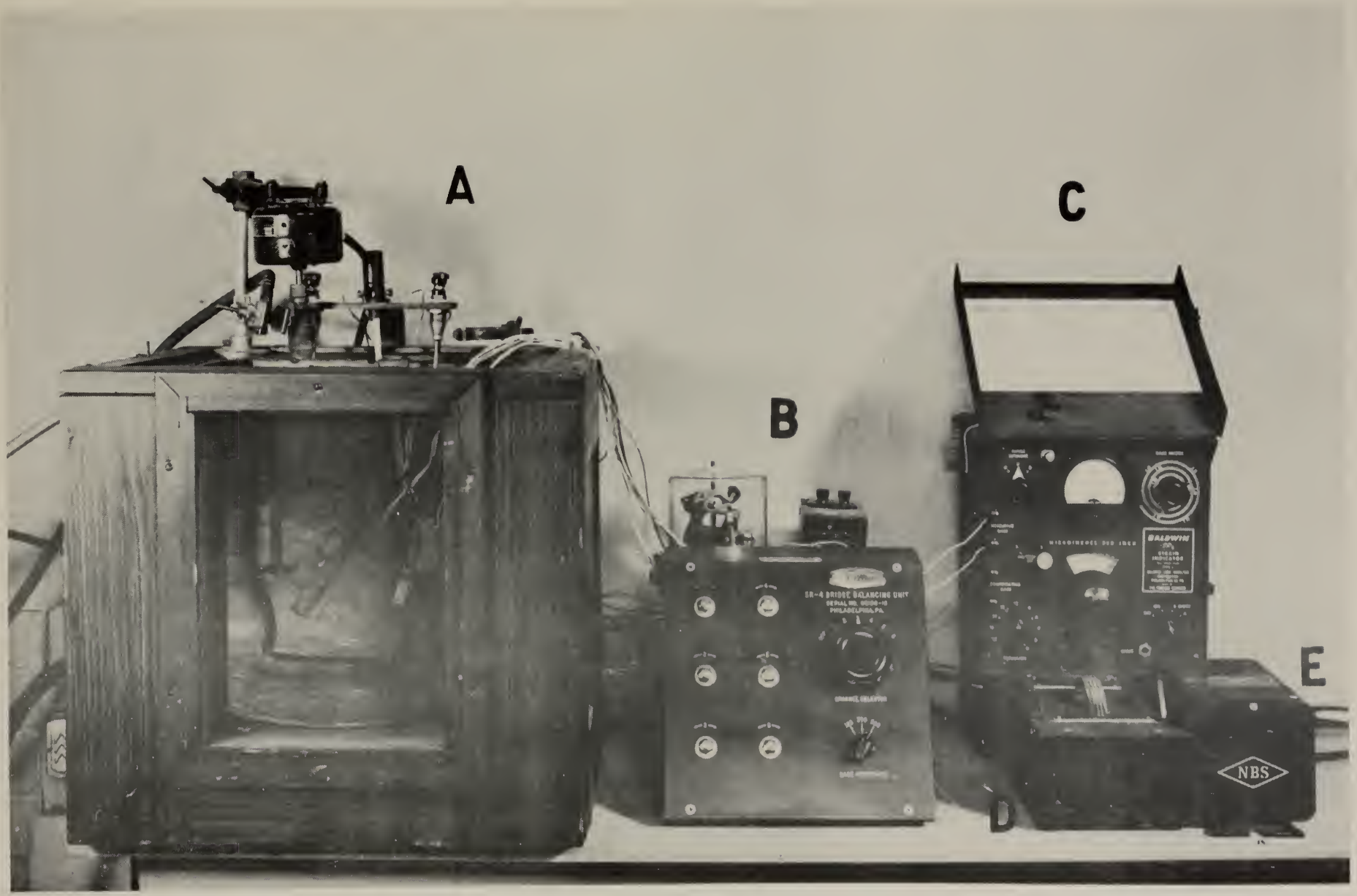
Figure 2. A. Water bath with its thermoregulator, stirrer, heater and immersed gages.
B. Mercury relay switch, 12 volt relay transformer and the gage balancing and switching unit.
C. Strain indicator.
D. The power supply for the indicator.
E. The constant voltage transformer for the power supply.


A
B
C
D
E
SR-4 BRIDGE BALANCING UNIT
BALDWIN
NBS

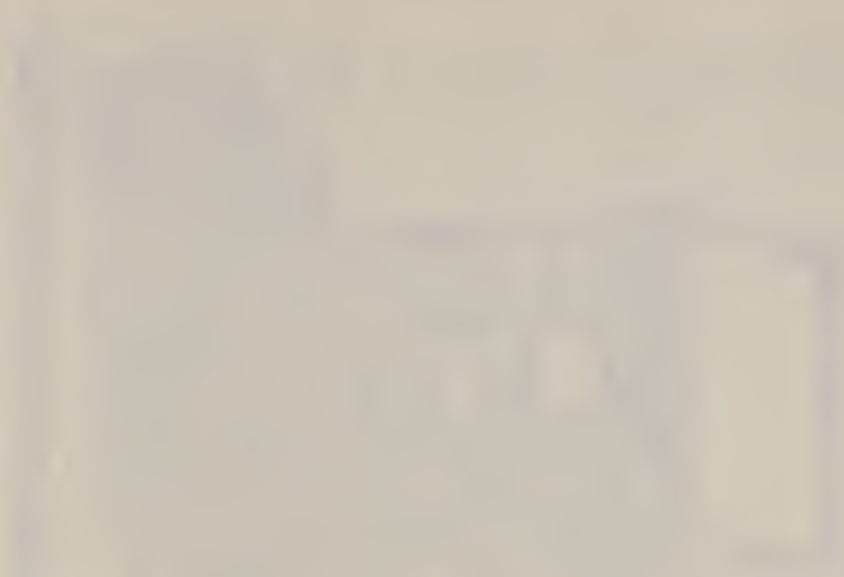


Figure 3. Flash mold used in preparing the specimen for investigation.

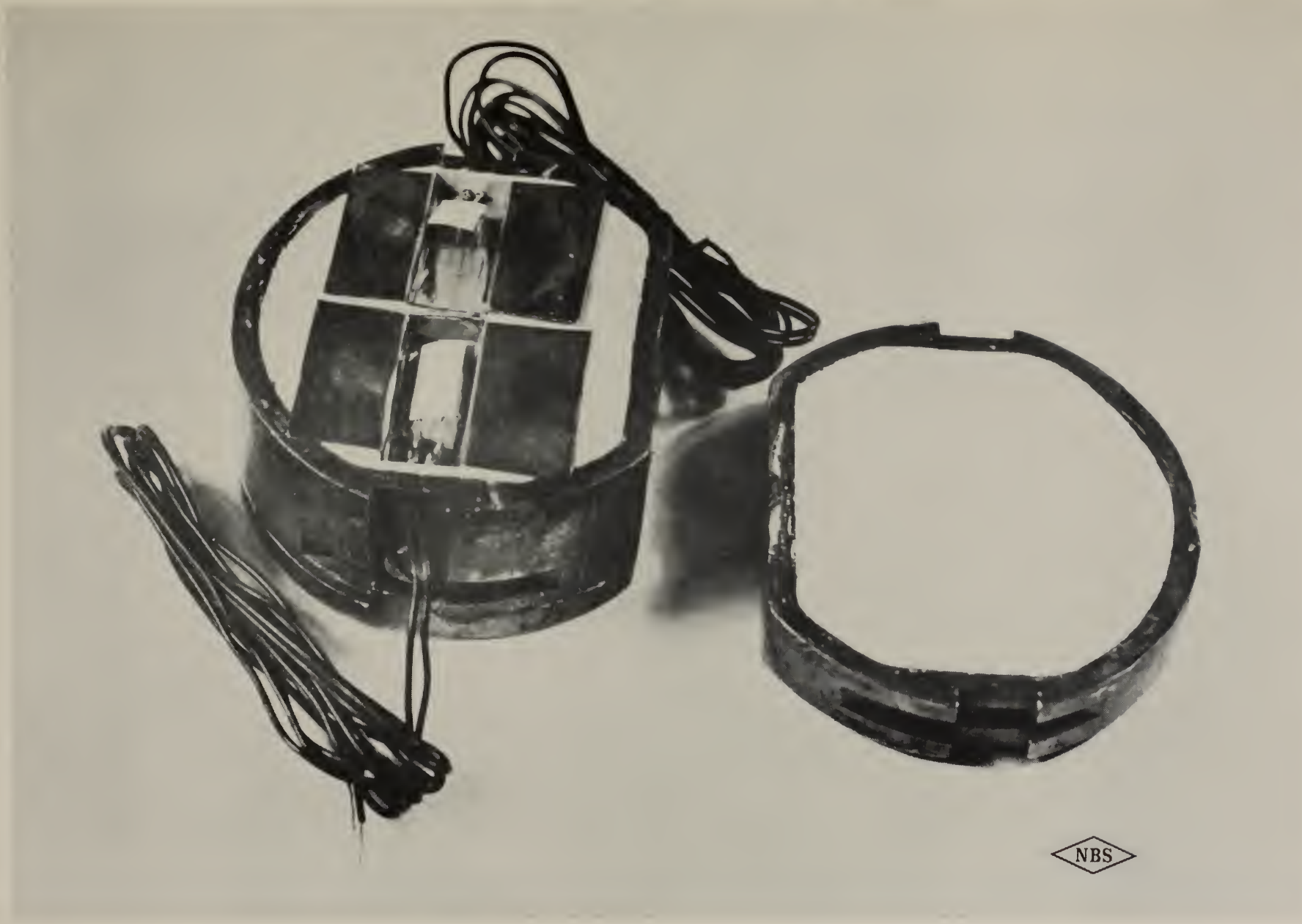

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Figure 4. This figure displays the general position of the gages in the specimens.

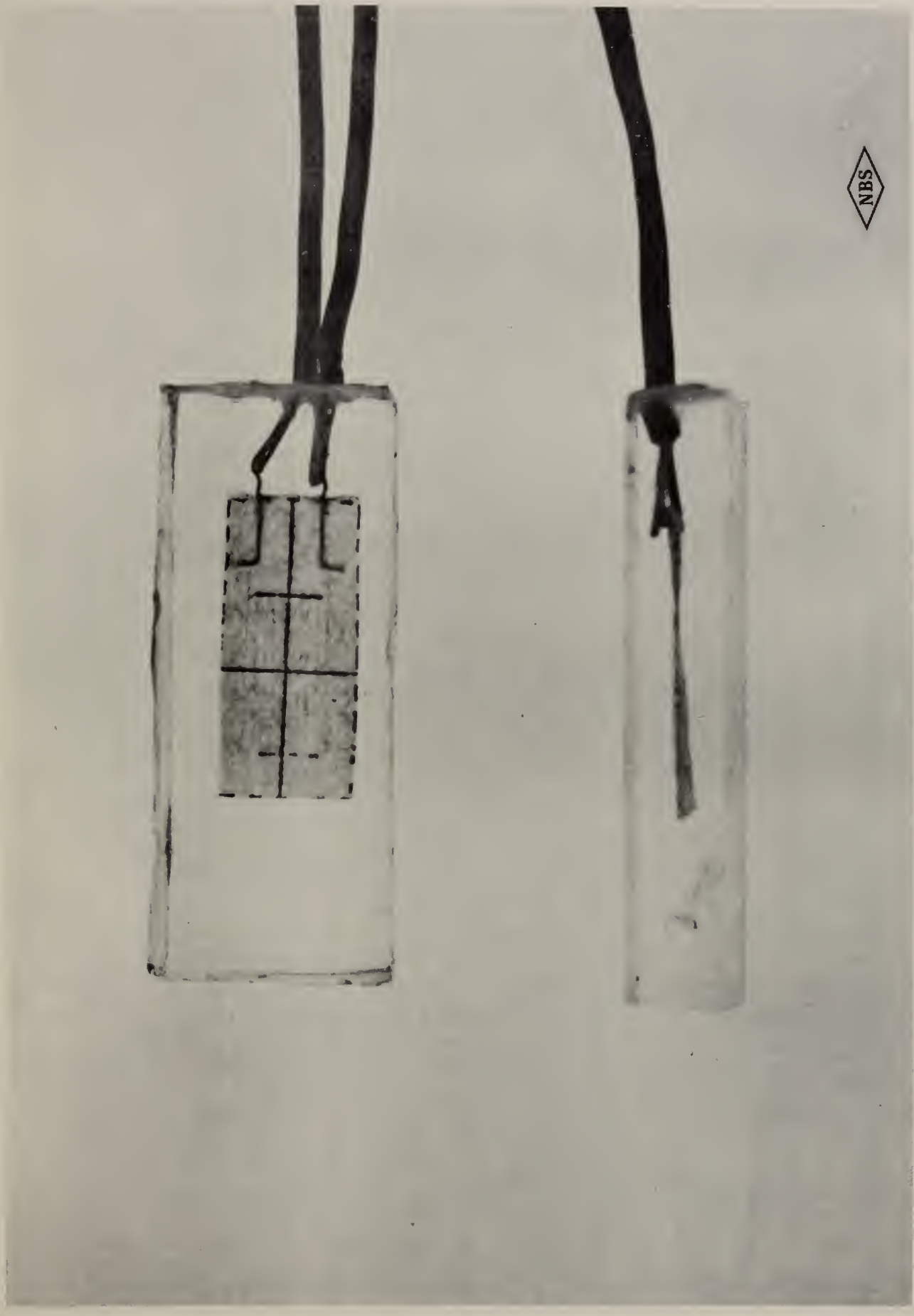
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Figure 5. A linear plot of the change in strain vs the time of immersion.

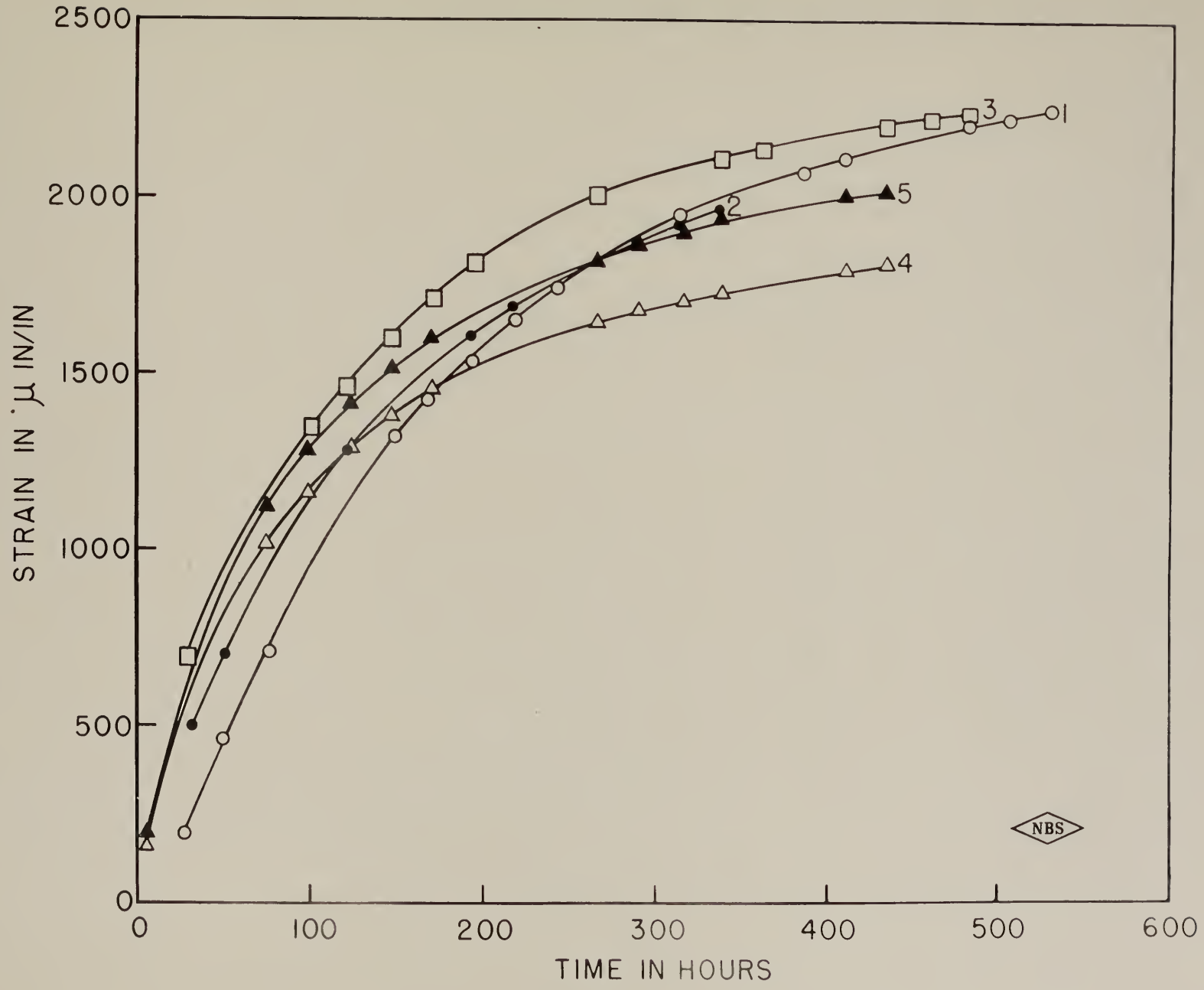

2500
2000
1500
1000
500
0
STRAIN IN 'μ IN/IN
0
100
200
300
400
500
600
TIME IN HOURS
1
2
3
4
5
NBS

Figure 6. A semi-logarithmic plot of the logarithm of the change in strain vs the time.

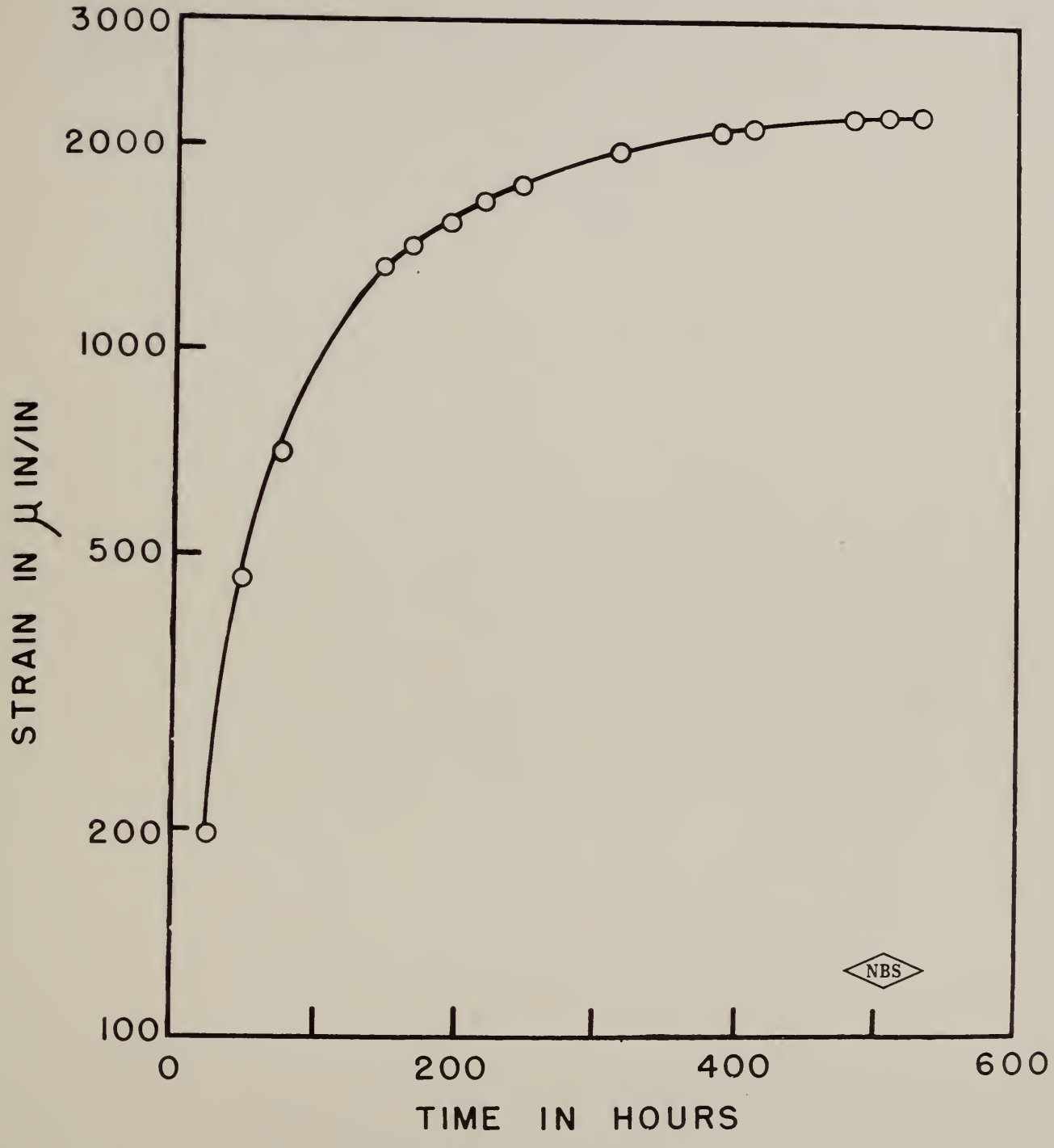
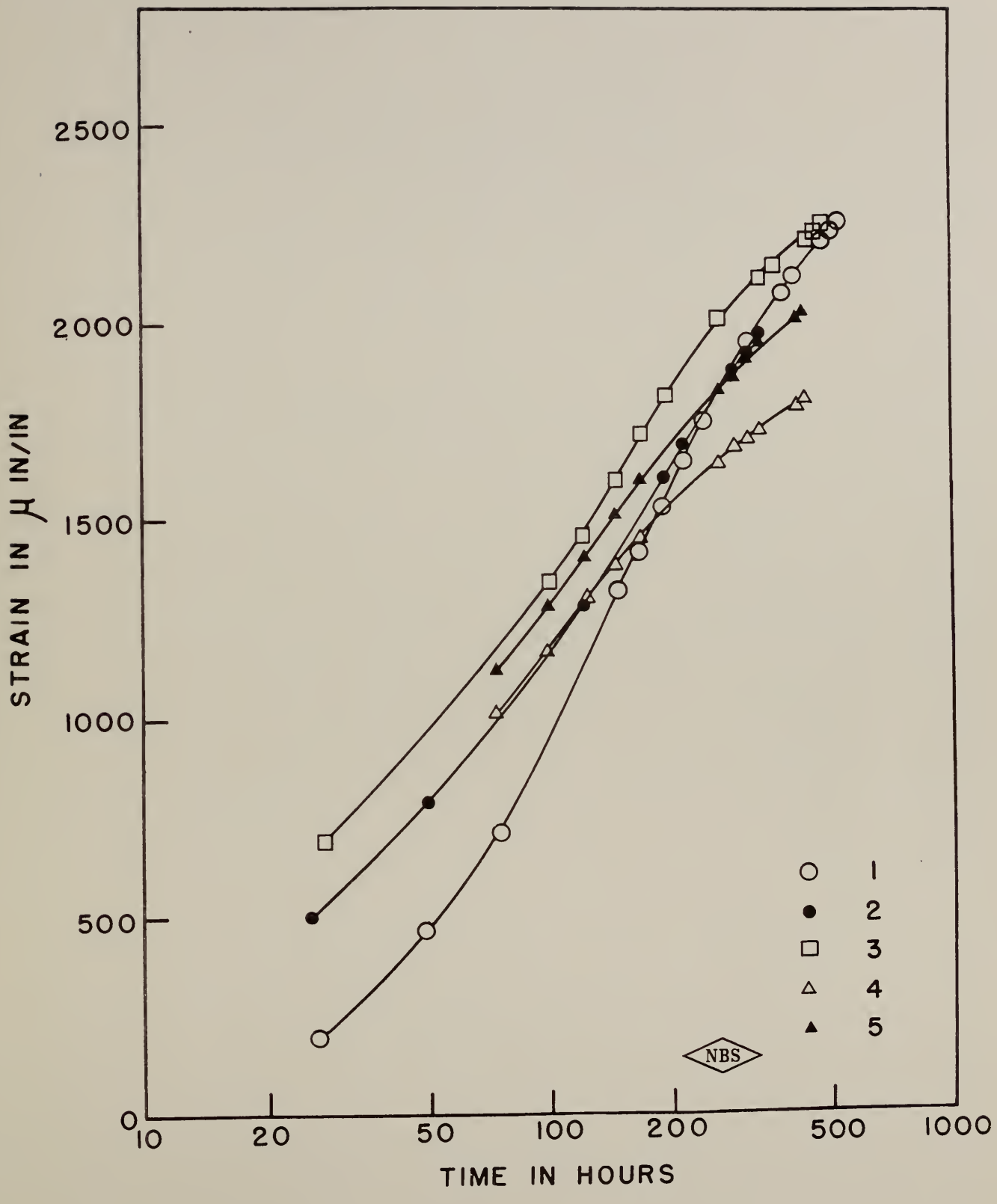

3000
2000
1000
500
200
100
STRAIN IN μ IN/IN
0
200
400
600
TIME IN HOURS
NBS

Figure 7. A semi-logarithmic plot of the change in strain vs the logarithm of the time.


2500
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STRAIN IN μ IN/IN
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TIME IN HOURS
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3
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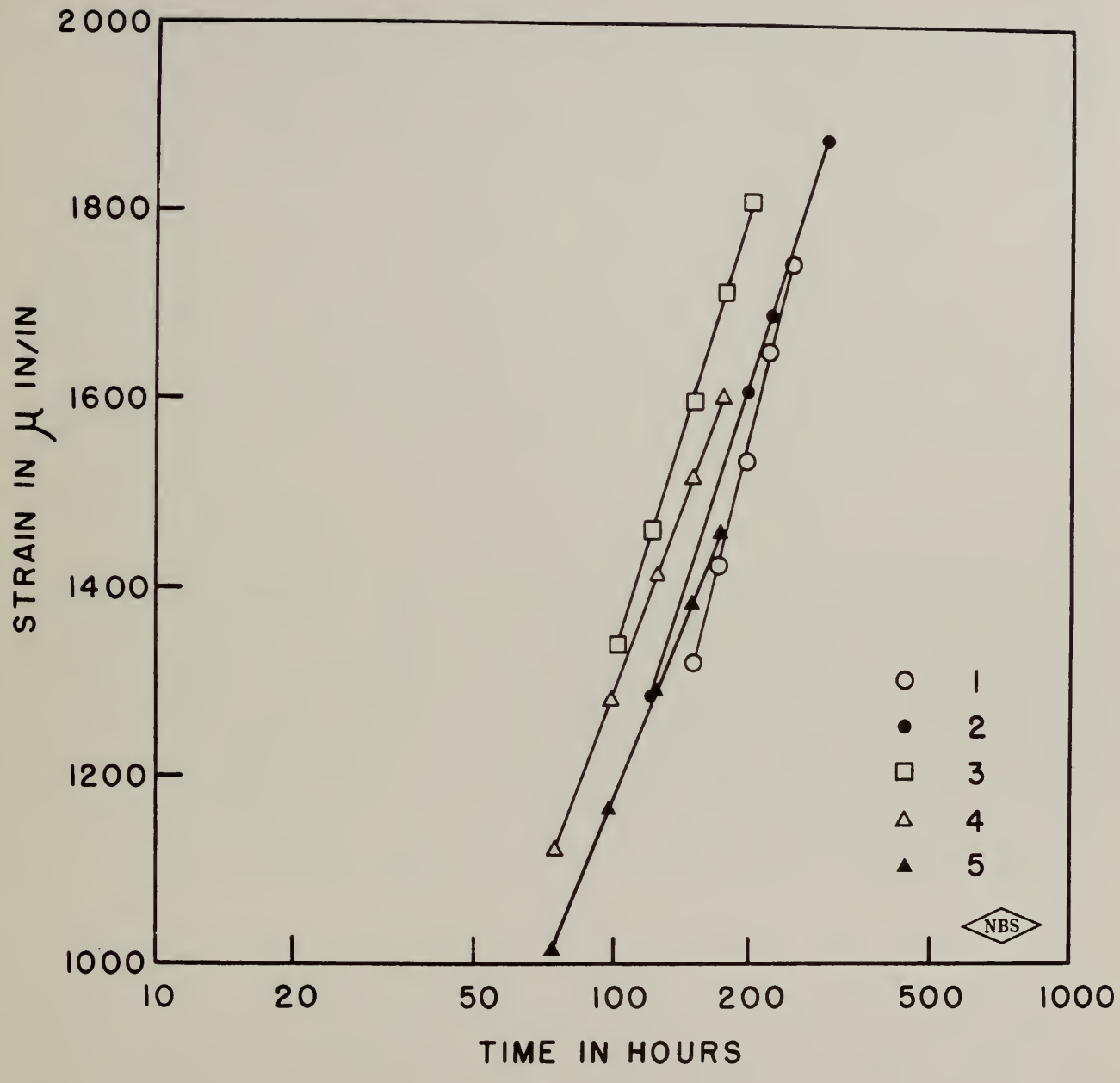
NBS

Figure 8. A semi-logarithmic plot of the change in strain vs the logarithm of the time.


2000
1800
1600
1400
1200
1000
STRAIN IN μ IN/IN
10
20
50
100
200
500
1000
TIME IN HOURS
1
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5
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